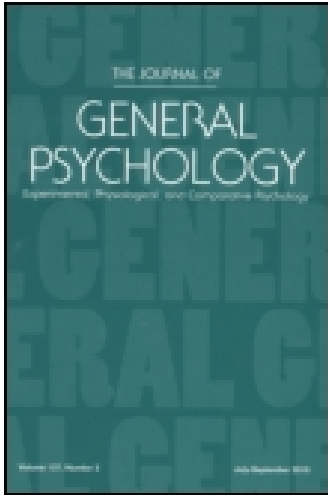




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Drive and Reflex Strength: II

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DRIVE AND REFLEX STRENGTH: II*

From the Psychological Laboratories and the Laboratory of General Physiology of Harvard University

B. F. SKINNER¹

It has been shown that the rate at which an albino rat of a particular strain eats uniform pieces of a standard food varies as a function of time from the beginning of an eating period, in such a way that the amount of food (N) already eaten at any time (t), measured from the beginning of a period, is given by the equation

$$N=Kt^n$$

where K and n are constants and n has a value lying between 0.68 and 0.70 (1,3). A rate of eating,² expressed as amount of food consumed per unit time, has only an indirect reference to the detailed behavior of the organism. A given rate is necessarily determined, however, by specific factors in behavior—of which the rate is, in consequence, a measure. Certain of these factors have been discussed elsewhere (1), and it has been found convenient to describe them and their changes in terms of the *strength* of the reflexes that are operative when a rat approaches, seizes, chews, and swallows a bit of food.

The stimuli for the initial members of this sequence of reflexes emanate from the food or the food tray. They act continuously. But the initial reflexes are not continuously elicited. In accordance with the principle of chaining, a first response will have supplied stimuli for the elicitation of succeeding responses, which carry the food to the mouth, chew and swallow it; and some at least of these later members of the chain utilize the effectors necessary for the initial responses and are prepotent over them. When the effectors are again free, the initial stimulus may take its effect.

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¹National Research Council Fellow.

²Since the eating progresses by discrete steps we are justified in dealing only with an average rate over a finite interval of time. It is often convenient, however, to obtain such a value by measuring the slope of a smoothed curve or by differentiating the equation given above.

Usually, however, a further interval may be observed before the initial reflexes are again evoked. During this interval the rat may stand quite still or may make incidental responses to parts of the apparatus. But it will not respond to the food or food tray, in spite of the fact that the stimulating energies arising from these sources are unchanged.³ The duration of such a period, under the conditions of the present experiments, may range from a second or two to several minutes. The termination is well marked: the initial response is elicited very suddenly, and the other members of the chain then follow in turn.

Such a period of irresponsiveness is by definition a refractory phase.⁴ And since, more specifically, it is the refractory phase of the initial reflex, its proper measure is the total interval between homologous points in the course of two successive elicitations. The actual eating behavior must be regarded as running concurrently with the first part of the phase and ordinarily, therefore, as playing no part in delaying the repetition of the initial response. Nevertheless, if for any reason the refractory phase is briefer than the eating time, the latter will determine the recorded interval. This may happen in two sorts of cases: (*a*) where the chain has been made unduly long, as, for example, by the addition of arbitrary members (see the case noted below), or (*b*) where the reflexes are very strong and the refractory phase consequently very brief. We need not consider these special cases here. In the experiments referred to (1,3) and in those to be described the intervals seem to be determined solely by the refractory phase. This is certainly true at the lower rates of eating, where the behavior is more easily inspected, and seems also to be true of the highest rates here dealt with, which

³It is not quite correct to say that the stimuli for the initial reflexes do not vary, for some such variation must result from the activity of the rat during the period of irresponsiveness. If the rat has been thoroughly conditioned to the apparatus, however, the effect of this activity is negligible, for the incidental "investigatory" responses have then in the main adapted out and every part of the apparatus will evoke responses carrying the rat to the food tray. In any event the only possible effect of such a variation in the intensity of the stimulus is to scatter the observed times for a group of comparable intervals, and this scatter is actually very small, as may be inferred from the accompanying records.

⁴The terms reflex, reflex strength, refractory phase, and so on are used here in accordance with the definitions discussed in (2). In the present case the distinction between a relative and an absolute refractory phase cannot be maintained, since a measure of the strength of the response or of the stimulus is lacking.

are by no means maximal. If the contrary were true—if at the higher rates the refractory phase were obscured by the eating time—the curve for a decline in rate should show a break where the phase emerges to control the interval. Nothing of this sort is observed, however. It is possible that the eating behavior may have some effect upon the refractory phase of the initial response (we have noted that common effectors are employed), but in such a case the measured interval is, nevertheless, still a refractory phase.

The presence of a refractory phase and its operation to control the rate of eating lends a special importance to the initial reflex and raises the question with which the present experiments are concerned. Is the law expressed in the equation $N=Kt^n$ independent of the particular reflex that initiates the eating behavior? The usefulness of the law will depend largely upon the answer; for while the later steps in the process of ingestion (chewing, swallowing, and so on) vary but little between comparable organisms, the early steps (which are *conditioned* reflexes) may show an infinite variety.

In the experiments previously reported, rats obtained food from a small tray. A lightly balanced door, necessary for recording the behavior, partly closed the opening to the tray, but after the usual adaptations had taken place, the presence of the door modified the behavior only slightly. In such an instance the act of eating a pellet of food began with certain reflexes of approach to the tray and food, which brought the lips of the rat into contact with the food and thus set up the subsequent reflexes of chewing and swallowing. The plan of the present experiment is to add an arbitrary initial member to this sequence. The food tray is accordingly replaced by a repeating "problem box," which delivers a pellet of food into an open trough each time a horizontal lever is pressed downward. The response to the lever is thus added to the sequence. In the present experiments the necessary conditioning has already been acquired. An account of the behavior during the conditioning period is reserved for a later communication.

II

The problem box is shown in Figures 1*A* and 1*B*. It is about 17 cm. high and is constructed of galvanized iron. The trough from which the rat eats is 9 cm. x 5 cm. at the top and 3.5 cm. deep. The sides slope inward and nearly meet at the bottom. The horizontal lever, which must be pushed about 1 cm. downward in ob-

taining food, is at rest 7 cm. from the floor. Its inside edge is free of the side of the box by about 6 mm. The shields at the corners of the box expose 8.5 cm. of the lever at the front and about 4 cm. at the sides. The sides may be ignored, for only the front section is used by the rat. The lever is held in its resting position by a spring, which is inside the box and is not shown in the drawings. The tension of the spring is adjusted until a weight of 10 gms. will just force the lever downward to the position at which a contact is made. The lever will move somewhat past this point. The mercury-cup contact is shown at *A* in Figure 1*B*. A food magazine, bolted to the back of the box, is also shown in Figure 1*B*. A piece of food discharged from it rolls forward into the trough, where it is accessible to the rat.

The construction of the magazine is shown schematically in Figures 1*B* and 1*C*. The magazine proper is an upright glass tube 90 cm. long. It holds about 130 pieces of a standard food (McCollum's formula). The food is prepared with a modified "pill-machine," which produces cylindrical pellets 7 mm. long and 3 mm. in diameter. They slide freely in the tube and are released from it one at a time by an electrically operated escapement, the plan of which is also given in the figures. In constructing the escapement two small holes about 8 mm. apart are ground into the tube at its lower end. Through these the ends of a small semicircular piece of spring wire (*B*) are free to pass. The middle of the wire is fastened to a soft-iron armature (*C*) which swings about an imaginary line passing through the center of the tube perpendicular to its long axis. The line also passes through the center of the semicircle of the wire. When the armature is in its resting position, as shown in Figure 1*B*, the lower end of the wire is in the tube. The column of food rests upon it. When the armature is drawn up by the magnet (*D*), the lower end is withdrawn from the tube and the upper inserted to press against the second piece of food. The first piece is released.

The method of recording has been described (1). A writing point, tracing upon a slow kymograph drum, is lifted vertically a single uniform step at each contact made at the problem box. The graph of a series of contacts is a step-like line, the slope of which (that is, the tangent of the angle with the horizontal) is a measure of the rate. The rates shown in the accompanying graphs vary by a factor

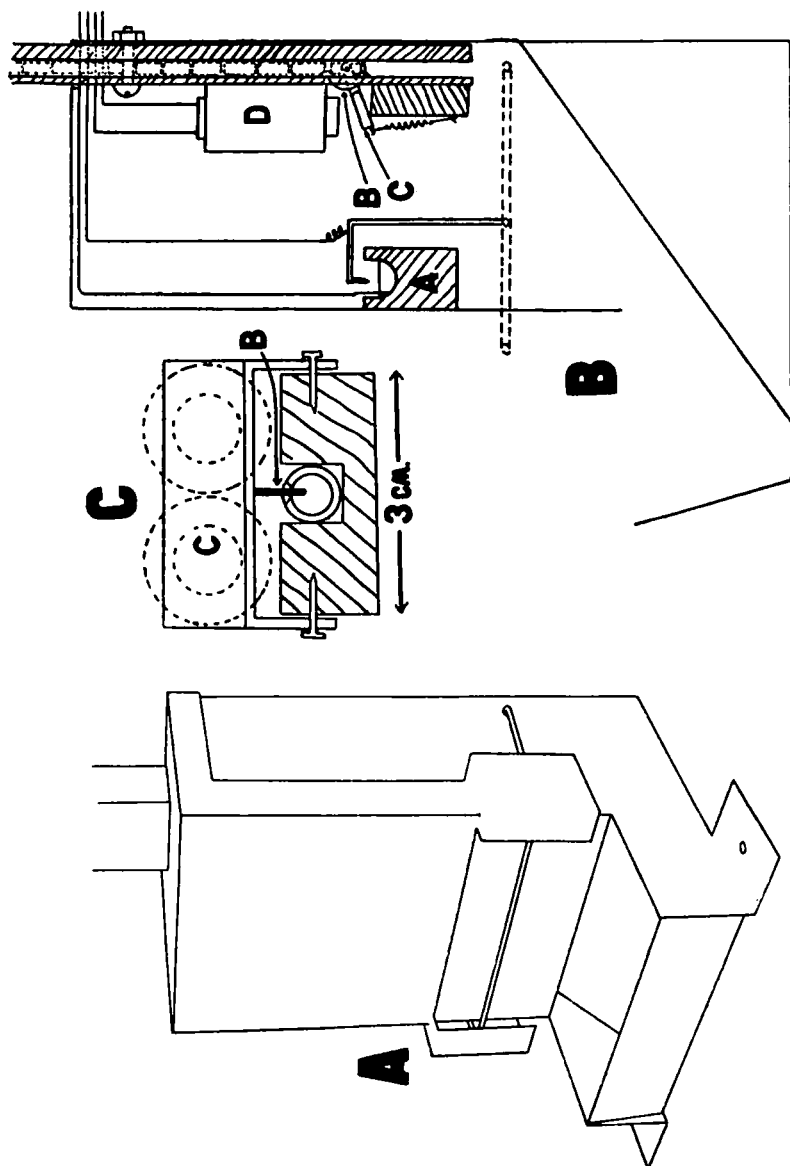


FIGURE 1

- A. Sketch of the problem box.
 B. Schematic section of the problem box, showing also the mercury-cup contact and the food magazine.
 C. Cross-section of the magazine and escapement. For details see text.

of about four. In order to avoid superfluous contacts due to the inexperience of the rat's manipulation of the lever, a device also previously described (1) is introduced into the circuit. Its effect is to break the circuit for a few seconds following each contact. In the wiring of the whole apparatus the solenoids of the magazine, recording device, and circuit-breaker are in parallel; the contacts in the problem box and circuit-breaker lie in series between the solenoids and a storage battery. To summarize the action of the apparatus:

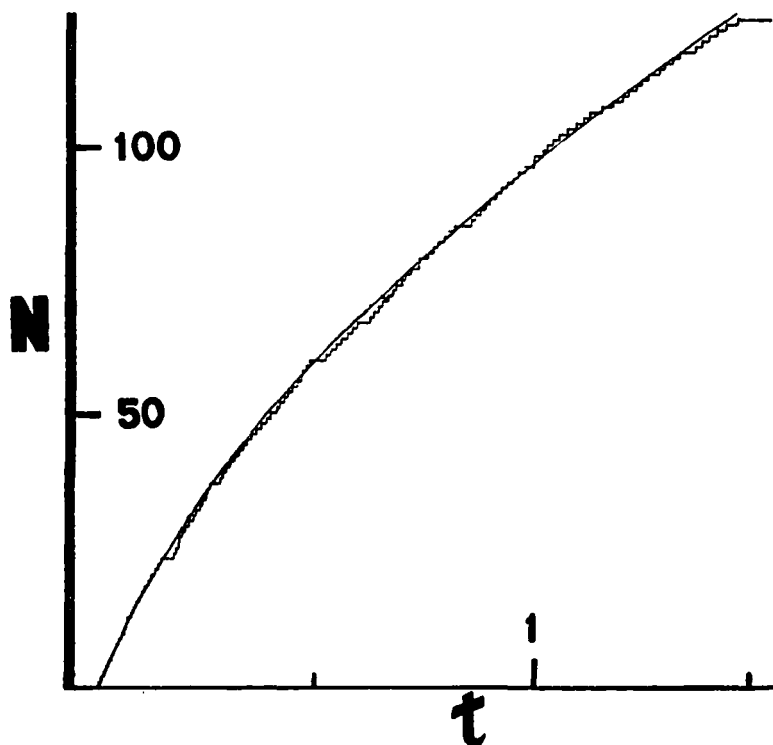


FIGURE 2

Kymograph record of the eating behavior of a white rat, where the pellets of food are obtained by pressing the lever of a problem box. N = number of pieces of food eaten; t = time from the beginning of the eating period in hours. The step-like curve is reproduced directly from the record. Coordinates and a theoretical curve have been added. The theoretical curve is for the equation $N=Kt^n$, where $K=2.0$ (units arbitrary) and $n=0.70$.

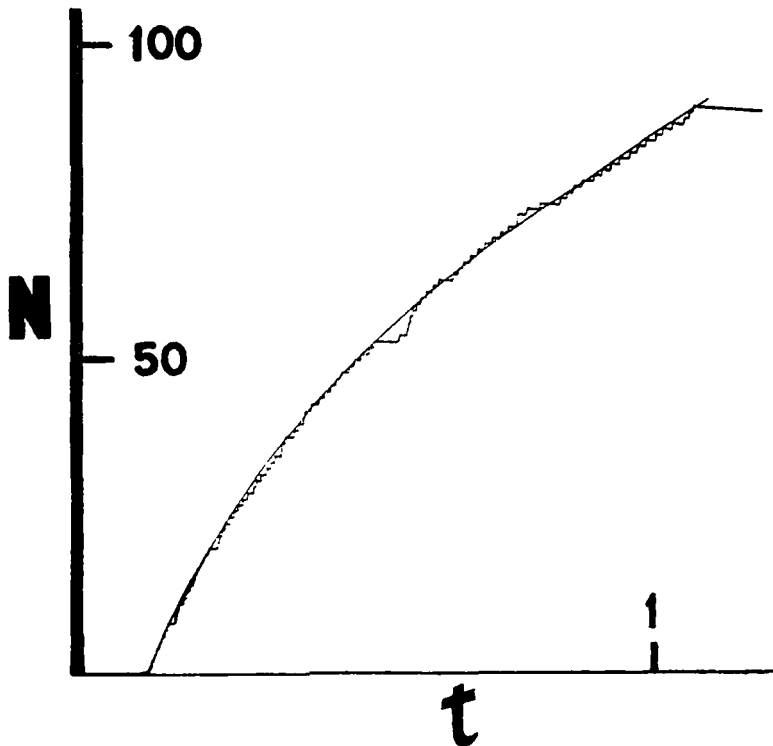


FIGURE 3

Kymograph record of the eating behavior of the same rat, where pellets of food are obtained from a tray. N = number of pieces of food eaten; t = time from the beginning of the period in hours. The curve is reproduced from the original record as in Fig. 2. The theoretical curve is for the same equation as in Fig. 2 and for the same value of n . In this figure $K=1.9$ (units as in Figure 2).

Note the delay and subsequent recovery midway along the curve.

when the rat presses the lever of the problem box, (a) a pellet of food is released into the trough, (b) the writing point is lifted one step, and (c) the whole circuit is thrown open for the following six or seven seconds.

The experimental procedure is in general as previously described (1). The problem box is placed in a sound-proof dark box 55 cm. x 50 cm. x 20 cm., which is continuously ventilated and contains a supply of water. At the same hour daily a rat is put into the box

and left there until a time at which no eating has taken place for about fifteen minutes. It is then removed, and except for about five grams of lettuce leaf no other food is given to it.

III

A typical record obtained with this method is given in Figure 2. The graph itself (the step-like line) and the t axis are reproduced directly from the kymograph record. The N axis and a theoretical curve have been added.⁵ The record describes the behavior of the rat for a period of an hour and a half, during which 124 pellets of food, weighing in all about eight grams, are eaten. It will be seen that the rate begins at a maximum and declines steadily throughout the period. The experimental curve follows very closely the theoretical curve drawn through the data. The latter is for the equation $N=Kt^n$, where $n=0.70$ and $K=2.0$.

For comparison a curve obtained with the same rat, but where food is taken from a tray described in (1), is given in Figure 3. The theoretical curve is for the same equation and for the same value of n . In this figure $K=1.9$.

The value of K depends upon several conditions of the experiment and upon the animal employed (3). In the same situation and with the same animal it changes from day to day.⁶ Consequently, the values here obtained (2.0 and 1.9) do not imply any essential difference between the curves. The constant n , on the other hand, has been found to be practically independent of the conditions of an experiment and of the animals employed (three generations of an inbred strain have now been tested). It is significant, therefore, that the same value of n is obtained in each of the present records. The two curves, that is to say, are practically identical.

A few special aspects of the records may be noted. The last horizontal line in each case might have been extended considerably to the right, for with the last recorded pellet the rat ceased eating

⁵When a record is taken, the vertical line described by the writing point is always ascertained to be at an angle of 90° with the horizontal.

Because of a reconstruction of the recording apparatus the units of the present record differ from those of the records previously published.

⁶In calculating the values of K and n a record is transferred to coördinate paper and the values of N and t are read directly in the units of the paper. The constant n is independent of this procedure. The value of K , however, depends upon the units chosen, and two values can be compared only if the procedure has been the same. The present magnitudes of K are not to be compared directly with those previously published.

altogether. The curves, therefore, end abruptly. This is typical of records obtained with either procedure. An example of another characteristic, which has already been discussed (1), is offered by Figure 3. At about the fiftieth piece of food the rat stops eating for a short period and consequently falls slightly behind the schedule set by the equation. The delay is followed, however, by a sharp acceleration, which brings the curve back to its proper position. After the first step, which is exceptional, the recovery curve is convex upward and remarkably uniform in its curvature. Note that its initial rate is greater than that of the beginning of the main record.

IV

In the two cases we have compared, then, the validity of the equation $N=Kt^n$ is independent of the nature of the initial reflex. And this seems to be true in spite of the fact that it is the elicitation of this reflex at the end of its refractory phase that determines the rate of eating. The two present responses, moreover, are quite unlike, and the broader conclusion seems warranted that the rate of change of the rate is in general independent of whatever reflex may initiate the behavior.

An obvious exception to this rule will arise if the added member consumes so much time that the maintenance of a high rate is impossible. A case of this sort has appeared in some unfinished experiments by M. F. Stevens and the writer. Here a rat is conditioned to run ten turns in a running wheel (a distance of approximately 60 feet), at the end of which a pellet of food is automatically delivered to a tray at the side of the wheel. The running must be repeated for each pellet. It is obvious that the higher rates at the beginning of the normal curve cannot be reached under these conditions. One obtains, therefore, a limiting slope at the beginning of the record. A more detailed account may be reserved until the experiments are completed.

The present result justifies a simplifying assumption made both in this and in the preceding paper (1). We have dealt with a rate of eating in terms of the characteristics of an initial reflex. As a matter of fact, there is no one initial reflex of this sort. We cannot control the behavior of the rat adequately enough to insure the administration of an invariable stimulus or the elicitation of an invariable response. The number of possible initial reflexes, even in the simple act of picking up a pellet of food, is therefore indefinite, for it corresponds to the number of possible ways in which the stimu-

lating energies emanating from the food may affect the organism. We are justified in speaking of *one* initial reflex only because the members of this indefinite group possess very much in common. In particular, they all affect the recording apparatus in the same way, and all lead to the same process of ingestion of the pellet. Why this diversity does not affect the regularity of the recorded behavior is made clear by the present result. The change in rate is independent of the precise nature of the initial reflex.

SUMMARY

At the normal rates of eating dealt with in certain experiments previously reported, a given rate is determined by the refractory phase of the reflex initiating the behavior. It is important to know whether the change in rate implied in the law $N=Kt^n$ is dependent upon the nature of this initial reflex.

The previous experimental procedure is modified, therefore, so that the rat obtains uniform pieces of food in operating a repeating problem box. The initial response to the lever of the problem box is thus added to the usual behavior.

The rate at which the lever is manipulated during an eating period is measured in the usual way. Typical curves obtained in both procedures are reproduced for comparison. Both are fitted with theoretical curves, which are for the same equation and the same value of n . The curves are thus essentially identical.

Conclusion. For the two reflexes here compared, and probably in general, the rate of change of the rate of eating is independent of the nature of the particular reflex with which the eating behavior begins.

I wish to express my indebtedness to the Department of Psychology, Harvard University, especially to Dr. Morgan Upton, for the space and facilities necessary for these experiments.

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L'IMPULSION ET LA FORCE DU RÉFLEXE: II

(Résumé)

Aux vitesses normales de manger étudiées en certaines expériences déjà rapportées une vitesse donnée est déterminée par la phase réfractaire du réflexe qui initie le comportement. Il est important de savoir si le changement de vitesse impliqué dans la loi $N = K t^n$ dépend de la nature de ce réflexe initial.

Le procédé expérimental antérieur est donc modifié, de sorte que le rat obtient des morceaux uniformes de nourriture dans son opération d'une boîte à problèmes qui se répètent. La réponse initiale au levier de la boîte à problèmes est ainsi ajoutée au comportement.

On mesure de la manière ordinaire la vitesse à laquelle le levier est manipulé pendant une période de manger. On reproduit pour la comparaison les courbes typiques obtenues dans les deux procédés. Les deux sont pourvus de courbes théoriques, qui sont pour la même équation et la même valeur de n . Les courbes sont ainsi essentiellement identiques.

Conclusion. Pour les deux réflexes ici comparés, et probablement en général, la vitesse du changement de la vitesse de manger ne dépend pas de la nature du réflexe avec lequel commence le comportement de manger.

SKINNER

TRIEB UND REFLEXENSTÄRKE, II

(Referat)

Bei normalen, in früher besprochenen Experimenten behandelten Fressschnelligkeiten (rates of eating) wird eine gewisse Schnelligkeit durch die refraktäre Phase des die Tätigkeit anregenden Reflexes bestimmt. Es ist wichtig festzustellen, ob die in dem Gesetz $N = Kt^n$ mit einbegriffene Aenderung der Schnelligkeit von der Beschaffenheit dieses anregenden Reflexes abhängig ist.

Das vorherige experimentelle Verfahren wird also so modifiziert, dass die Ratte gleichförmige Stücke Nahrung bei der Handhabung eines widerkehrenden Aufgabekastens (repeating problem box) erhält. Die Anfangsreaktion (initial response) auf den Hebel des Aufgabekastens wird also der Tätigkeit zugefügt.

Die Schnelligkeit, mit der der Hebel während einer Fressperiode gehandhabt wird wird auf die gewöhnliche Weise gemessen. Es werden typische, mit beiden Verfahren erhaltene Kurven zur Vergleichung wiedergegeben. Beiden werden theoretische Kurven angepasst, die der selben Gleichung und dem selben n -Wert angehören. Die Kurven sind also wesentlich die gleichen.

Schluss: Bei den zwei hier verglichenen Reflexen, und wahrscheinlich im Allgemeinen, ist die Schnelligkeit der Veränderung der Fressschnelligkeit von der Beschaffenheit des bestimmten Reflexes, mit der die Fressstätigkeit anfängt unabhängig.

SKINNER